AGRICULTURAL ECONOMICS

Agricultural Economics 39 (2008) supplement 431–441

Is a slowdown in agricultural productivity growth contributing to the rise in commodity prices?

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Received 22 August 2008; received in revised form 17 September 2008; accepted 21 September 2008

Abstract

A slowdown in the rate of agricultural productivity growth is thought by many observers to be contributing to the recent rise in agricultural prices. In this article I decompose sources of output growth in global agriculture into aggregate input and total factor productivity (TFP) components and examine whether productivity growth slowed substantially in the years leading up to the recent rise in commodity prices. Contrary to widely held perceptions, I find no evidence of a general slowdown in sector-wide agricultural TFP, at least through 2006. If anything, the growth rate in agricultural TFP accelerated in recent decades. However, the results do show a slowdown in the growth of agricultural investment. Accelerating TFP growth largely offset decelerating input growth to keep the real output of global agriculture growing at about 2% per year since the 1960s. Regionally, however, agricultural productivity performance has been uneven. These findings have important implications for the appropriate supply-side policy response to the current agricultural price crisis.

JEL classification: O47, O57, Q10

Keywords: Agricultural land quality; Agricultural cost shares; Slow growth accounting; Total factor productivity (TFP)

1. Introduction

Most of the attention as to why agricultural prices have risen since 2006 has focused, probably rightly, on demand-side factors, especially the growing demand for grain-intensive meat in developing countries and for biofuels. However, supply-side factors, such as insufficient investment in agricultural capital and a slowing rate of productivity growth, have also received mention as likely contributing factors. The World Bank's most recent World Development Report 2008 detailed a dropoff in development aid for agriculture since the 1980s and described a declining growth in grain yields in developing countries (World Bank, 2007, Fig 2.12, p. 67). Both the *The Economist* (17/04/2008) and the *Financial Times* (01/06/2008) cited this slowing growth rate for cereal yield as one factor behind the recent rise in food prices, and supported this conclusion with expert opinion, such as the view of Lennart Bage, president of IFAD, that "The foundation of the current crisis is the slowdown in farm productivity" (quoted in the *Financial Times*, 01/06/2008). Trostle (2008) also attributed a slowing rate of productivity growth as contributing to several years of demand/supply imbalance in the global food economy, evidenced by the halving of global grain reserves during 2001–2007. In a study commissioned by the U.S.-based Farm Foundation, Abbott et al. (2008) reviewed more than 25 reports and studies of the current crisis in food prices, and highlighted a "lower level of investment in agricultural research leading to lower growth in productivity in commodity production," as a widely accepted conclusion. However, none of these studies actually assessed historical patterns of agricultural productivity growth, other than referring to the trend in cereal yield described in the World Development Report 2008. This trend showed average combined yield of rice, wheat, and maize in developing countries growing at about 2% per year during 1970–1990 and at about 1% per year during 1990–2007. But this is hardly sufficient evidence to conclude that global agricultural productivity growth substantially slowed. For one, the limitations of partial measures like crop yield for drawing inferences about long-run trends in productivity are well known, for they lump together a broad range of intensification processes. Moreover, the decline in global cereal reserves since 2001 (with ending stocks falling from around 600 million tons to under 300 million tons by 2007) was mostly due to a deliberate policy on the part of China to reduce an excessively large grain surplus it had accumulated in the 1990s (Huang et al., 2008; Ray, 2008). And

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 DOI: 10.1111/j.1574-0862.2008.00349.x

most importantly, a rigorous analysis of agricultural productivity trends should examine the whole sector, not just one group of commodities in one part of the world, since the current rise in agricultural commodity prices has extended far beyond cereal grains.[1]

Previous research on global agricultural TFP growth gives a mixed picture. Many studies have relied on distance function measures like the Malmquist Index to compare productivity among groups of countries. Recently, Ludena et al. (2007) used this method to estimate agricultural productivity growth for 116 countries, and found that average annual agricultural TFP growth increased from 0.6% to 1.29% between 1961–1980 and 1981–2000. But this methodology is sensitive to the set of countries included for comparison (Coelli and Rao, 2005) and the number of variables in the model, or the dimensionality issue (Lusigi and Thirtle, 1997). Studies using index number methods, which require more data, have usually been limited to single countries, and these are also sensitive to context. In a comparison of economic growth between India and China between 1978 and 2004, Bosworth and Collins (2008) show a decline in Indian agricultural TFP after 1993 while China's remained constant. Fuglie (2004) found evidence of stagnating TFP growth in Indonesian agriculture during the 1990s, while Fuglie et al. (2007) found no evidence of long-run decline in U.S. agricultural TFP growth through 2004. Latin America agriculture, according to Avila (2007), experienced generally higher productivity growth during 1981–2000 than during 1961–1980, but with mixed trends for individual countries. These country and regions studies provide little guidance for assessing trends in global agricultural productivity growth.

The objective of this article is to examine long-run productivity trends in the global agricultural sector and determine whether a productivity slowdown may have contributed to the recent rise in commodity prices. I use an index number approach to measure changes in global agricultural total factor productivity (TFP) from 1961 to 2006 and examine whether agricultural productivity growth slowed substantially in the years leading up to the recent rise in commodity prices. Although I am not able to examine TFP changes since 2006, any major deviation from trends since then would most likely reflect short-run (weather-induced) supply shocks rather than an abrupt change in underlying resource productivity.

2. Measuring TFP in agriculture

2.1. Methods for TFP measurement

Productivity statistics compare changes in outputs to inputs in order to assess the performance of a sector. Two types of productivity measures are partial and multifactor indices. Partial productivity indices relate output to a single input, such as labor or land. These measures are useful for indicating factor-saving biases in technical change but are likely to overstate the overall improvement in efficiency because they do not account for changes in other input use. For example, rising output per worker may follow from additions to the capital stock and higher crop yield may be due to more application of fertilizer. For this reason, a measure of TFP relating output to all of the inputs used in production gives a better indicator of a sector's efficiency than indices of partial productivity.

TFP is usually defined as the ratio of total output to total inputs in a production process. In other words, TFP measures the average product of all inputs. Let total output be given by Y and total inputs by X. Then TFP is simply

$$TFP = Y/X. \tag{1}$$

Changes in TFP over time are found by comparing the rate of change in total output with the rate of change in total input. Expressed as logarithms, changes in Eq. (1) over time can be written as

$$\frac{d\ln(TFP)}{dt} = \frac{d\ln(Y)}{dt} - \frac{d\ln(X)}{dt}, \tag{2}$$

which simply states that the rate of change in TFP is the difference in the rate of change in aggregate output and input.

In agriculture, output is a composed of multiple commodities produced by multiple inputs, so Y and X are vectors. Chambers (1988) shows that when the underlying technology can be represented by a Cobb–Douglas production function and where (i) producers maximize profits so that output elasticities equal input shares in total cost and (ii) markets are in long-run competitive equilibrium so that total revenue equal total cost, then Eq. (2) can be written as

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right), \tag{3}$$

where R_i is the revenue share of the ith output and S_j is the cost-share of the jth input. Output growth is estimated by summing over the output growth rates for each commodity after multiplying each by its revenue share. Similarly, input growth is found by summing the growth rate of each input, weighting each by its cost share. TFP growth is just the difference between the growth in aggregate output and aggregate input. The principal difference between this index measure of TFP growth and a more general TFP productivity measure, such as the Tornqvist–Thiel index, is that here revenue and cost shares are held constant while in a Tornqvist–Thiel index these parameters may vary over time. Using fixed revenue and factor shares could potentially give rise to "index number bias" in cases where either the revenue or cost shares are changing significantly. It should be pointed out as well that cost shares are partly dependent on output prices themselves, since a part of agricultural output is used as inputs (seed and feed) in production.

[1] According to the IMF commodity price database, between January 2006 and June 2008 the international trade prices of cereal grains, annual and perennial oilcrops, tropical beverages, meats (except beef), rubber, cotton, wool, jute, oranges, and banana all rose substantially faster than the U.S. Producer Price Index. The only crop and livestock commodities that did not (out of more than 30) were beef, hides, sugar, and olive oil.

A key limitation in using Eq. (3) for measuring agricultural productivity change is that we lack data on input cost shares for most countries. There is simply no internationally comparable information on input prices, especially for nontraded inputs such as land and labor. Some studies have circumvented this problem by estimating a distance function, such as a Malmquist index, which measures productivity using data on input quantities alone (Coelli and Rao, 2005). But this method is sensitive to aggregation issues as well as data quality (especially, differences in agricultural land quality across countries) and can give unbelievably high or negative growth rates. To address this problem I use the approach developed by Avila and Evenson (2004), who constructed careful estimates of input cost shares for two large developing countries (India and Brazil) from representative farm survey data and from these derived representative cost shares for other developing countries. I extend this approach by assembling cost share estimates for five additional countries (China, Indonesia, Japan, the United Kingdom, and the United States) and then assume that these cost shares are representative of agricultural production for different groups of countries. I describe this more thoroughly in the section on “input cost shares” below.

To summarize, the theory underpinning the TFP productivity index assumes that producers maximize profits so that the elasticity of output with respect to each input is equal to its factor share. It also assumes that markets are in long-run competitive equilibrium (where technology exhibits constant returns to scale) so that total revenue equals total cost. If the underlying production function is Cobb–Douglas, then our index is an exact representation of Hicks-neutral technical change.

2.2. *Output and input data*

To assess changes in agricultural productivity over time I use FAO annual data on agricultural outputs and inputs over 1961–2006 and in some cases augment these data with updated or improved statistics from other sources. Although we cannot yet estimate TFP changes for 2007 and 2008 (the period when agricultural prices experienced rapid inflation) we should expect to see evidence of a slowdown in productivity growth in the years preceding the recent price rises, if in fact such a slowdown occurred—the reason being that productivity is a long-run phenomenon that reflects the underlying production technology and is unlikely to contract abruptly.

For output, FAO publishes data on production of crops and livestock and aggregates these data into a production index using a common set of commodity prices based on the 1999–2001 period. What is important for estimating output growth are the *relative* prices of these commodities (since this determines the weights on the commodity growth rates used for deriving the growth rate for total output). In relative terms, the 1999–2001 FAO commodity prices are fairly close to the “wheat equivalent” prices developed by Hayami and Ruttan (1985, p. 453–454) in their seminal study on international agricultural productivity (the FAO prices have a correlation coefficient of 0.86 with the Hayami–Ruttan wheat-equivalent prices). The FAO index of real output excludes production of forages but includes crop production that may be used for animal feed.

To disentangle long-run trends from short-run fluctuations in output (due to weather and other disturbances), I smooth the output series using the Hodrick–Prescott filter setting $\lambda = 6.25$ for annual data as recommended by Ravn and Uhlig (2002). This filter is commonly used to remove short-run fluctuations from macro economic time series in business cycle analysis. However, this process does not completely remove the effects of multi-year shocks, so it is still necessary to evaluate observed changes in the rate of TFP growth with auxiliary information about extended periods of unusual weather or other disturbances.

For agricultural inputs, FAO publishes data on cropland (rainfed and irrigated), permanent pasture, labor employed in agriculture, animal stocks, the number of tractors in use, and inorganic fertilizer consumption. For fertilizer input and for selected large producers (China, Brazil, and Indonesia) I supplement FAO statistics with more recent national data on agricultural inputs. The International Fertilizer Association (2008) has more up-to-date and accurate statistics on fertilizer consumption by country than FAO. A relatively comprehensive dataset on China’s agriculture is available from the Economic Research Service (with original data coming from the State Statistics Bureau of the People’s Republic of China). For Brazil, I use results of the recently published 2006 Brazilian agricultural census (IPGE, 2008) and for Indonesia, Fuglie (2007) compiled improved data on agricultural land and machinery use. These sources together provide a set of global agricultural output and input data for 1961–2005, and for all but land and labor for 2006. To derive preliminary land and labor estimates for 2006 I apply the average annual growth rate from 2002–2005 of these inputs to their 2005 levels. Since aggregate agricultural land and labor usage historically has changed only slowly over time, this extrapolation will likely give a reasonable approximation for 2006.

Inputs are divided into five categories. *Farm labor* is the total economically active population (males and females) in agriculture. *Agricultural land* is the area in permanent crops (perennials), annual crops, as well as permanent pasture. Cropland (permanent and annual crops) is further divided into rainfed cropland and irrigated cropland. I also derive a quality-adjusted measure of agricultural land that gives greater weight to irrigated cropland and less weight to permanent pasture in assessing agricultural land changes over time (see the next section on “land quality” below). *Livestock* is the aggregate number of animals in “cattle equivalents” held in farm inventories, and include cattle, camels, water buffalos, horses, and other equine species (asses, mules and hinnies), small ruminants (sheep and goats), pigs, rabbits, and poultry species (chickens, ducks, and turkeys), with each species weighted by its size. The weights for aggregation from Hayami and Ruttan (1985, p. 450) are as follows: 1.38 for camels, 1.25 for water buffalo and horses, 1.00 for cattle and other equine species, 0.25 for pigs, 0.13 for small ruminants, 25 per 1,000 rabbits, and 12.50 per 1,000 head of poultry. *Fertilizer* is amount of major inorganic nutrients applied to agricultural land annually, measured as metric tons of N, P_2O_5, and K_2O equivalents. *Farm machinery* is the number of riding tractors in use.

While these inputs account for the major part of total agricultural input usage, there are a few types of inputs for which complete country-level data are lacking, namely, use of chemical pesticides, seed, prepared animal feed, veterinary pharmaceuticals, other farm machinery, energy, and farm buildings. However, data on many of these inputs are available for the seven country case studies I use for constructing the representative input cost shares. To account for these inputs I assume that their growth rate is correlated with one of the five input variables described above and include their cost in the related input: services from capital stock in farm buildings as well as irrigation costs are included with the agricultural land cost share; the cost of chemical pesticide and seed are included with the fertilizer cost share; costs of animal feed and veterinary medicines are included in the livestock cost share, and other farm machinery and energy costs are included in the tractor cost share. So long as the growth rates for the observed inputs and their unobserved counterparts are similar, then the model captures the growth of these inputs in the aggregate input index.

2.3. Land quality

The FAO agricultural database provides time series estimates of agricultural land by country and divides these estimates into cropland (arable and permanent crops) and permanent pasture. It also provides an estimate of irrigated area. Land quality between classes, and between countries, can be very different, however. For example, some countries count vast expanses of semiarid lands as permanent pastures even though these areas produce very limited agricultural output. Using such data for international comparisons of agricultural productivity can lead to serious distortions, such as significantly biasing downward the econometric estimates of the production elasticity of agricultural land (Craig et al., 1997; Peterson, 1987). In two recent studies of international agricultural productivity, Craig et al. (1997) and Wiebe et al. (2003) made considerable effort to include in their regression models variables that could account for differences in land quality (such as indices of average rainfall and soil type, the proportion of irrigated or pastureland in total agricultural land, and fixed effect models with regional or country dummies) with some success.

In this study, because I only estimate productivity growth rather than productivity levels, differences in land quality across countries is less problematic. The estimates only depend on changes in agricultural land and other input use over time. However, a bias might arise if changes occur unevenly among land classes. For example, adding an acre of irrigated land would likely have considerably more importance than adding an acre of rainfed cropland or pasture, and should therefore be given greater weight in measuring input changes. To account for differences in land type, I derive weights for irrigated cropland, rainfed cropland, and permanent pasture based on their relative productivity, and allow these weights to vary regionally. In order not to confound the land quality weights with productivity change itself, the weights are estimated using country-level data from the beginning of the period of study (i.e., I use average annual data for the 1961–1965 period). I first construct regional dummy variables ($\mathrm{REGION_i}$, $\mathrm{i} = 1 \ldots 5$, representing Asia-Pacific, Latin America and the Caribbean, Sub-Saharan Africa, Middle East and North Africa, and developed countries), and then regress the log of agricultural land yield against the proportions of agricultural land in rainfed cropland (CROP), permanent pasture (PASTURE), and irrigated cropland (IRRIG). Including slope dummy variables allows the coefficients to vary across regions

$$\ln\left(\frac{Ag\ output}{Cropland + Pasture}\right) = \sum_i \alpha_i (CROP^* REGION_i) + \sum_i \beta_i (PASTURE\ {}^*REGION_i) + \sum_i \gamma_i (IRRIG^* REGION_i). \tag{4}$$

The coefficient vectors $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, and $\boldsymbol{\gamma}$ provide the quality weights for aggregating the three land types into an aggregate land input index. Essentially, Eq. (4) asserts that countries with a higher proportion of irrigated land are likely to have higher average land productivity, as will countries with more cropland relative to pasture land, and that these differences provide a ready means of weighting the relative qualities of these land classes.[2]

The results of this land quality adjustment are shown in Table 1. On average, one hectare of irrigated land was more than twice as productive as rainfed cropland, which in turn was 10–20 times as productive as permanent pastures. When summed by their raw values, total global agricultural land expanded by about 10% between 1961 and 2005, with nearly all of this expansion occurring in developing countries. When adjusted for quality, "effective" agricultural land expanded by nearly double this rate. Globally, irrigated cropland expanded by 141 million hectares and this accounted for virtually all of the change in "effective" agricultural land over this period. For

[2] This approach to account for land quality is similar to one developed by Peterson (1987), who developed an international land quality index by regressing average cropland values in U.S. states against the share of irrigated and unirrigated cropland and long-run average rainfall. He then applied these regression coefficients to data from other countries to derive an international land quality index. The advantage of my model is that it is based on international rather than U.S. land yield data and provides results for a larger set of countries. The results give similar country rankings to average land quality as the Peterson index but shows wider variability in average land quality across countries.

Table 1
Global agricultural land use changes

Region	Rainfed cropland			Irrigated cropland			Permanent pasture			Total agricultural land		
	1961	2005	% change	1961	2005	% change	1961	2005	% change	1961	2005	% change
Raw totals (millions of hectares)												
Developed countries	363	345	−5	27	44	63	886	805	−9	1,276	1,194	−6
Developing countries	626	685	9	99	209	111	1,871	2,215	18	2,596	3,109	20
Former USSR countries	279	226	−19	11	25	127	332	382	15	622	633	2
World	1,268	1,256	−1	137	278	103	3,089	3,402	10	4,494	4,936	10
Quality adjusted (millions of hectares of "rainfed cropland equivalents")												
Developed countries	363	345	−5	58	94	63	84	76	−9	504	515	2
Developing countries	626	685	9	247	522	111	53	63	18	926	1,270	37
Former USSR countries	279	226	−19	24	54	127	31	36	15	334	316	−5
World	1,268	1,256	−1	329	670	104	168	175	4	1,765	2,101	19

Source: Agricultural land area from FAO, with adjustments made for Indonesia, China, and Brazil. Land quality adjustments from author's regressions (see text).

the purpose of our TFP calculation, accounting for the changes in the quality of agricultural land over time should increase the growth rate in aggregate agricultural input and commensurately reduce the estimated growth in TFP.

2.4. Input cost shares

To derive input cost shares I draw upon other studies that reported carefully measured input cost share calculations for selected countries and then I use these cost shares as "representative" of agriculture in different regions of the world. In Table 2 I show the input cost shares from the seven country studies (four developing countries: India, Indonesia, China, and Brazil, and three developed countries: Japan, the United Kingdom, and the United States). The table also shows the regions to which the various cost-share estimates were applied for constructing the aggregate input index. For example, the estimates for Brazil were applied to Latin American and Caribbean countries, North African and Middle Eastern countries, and South Africa, and the estimates for India were applied to other countries in South Asia as well as countries in Sub-Saharan Africa other than South Africa. These assignments were based on judgments about the resemblance among the agricultural sectors of these countries. Countries assigned to cost shares from India, for example, tended to be low-income countries using relatively few modern inputs. Countries assigned to the cost shares from Brazil tended to be middle-income countries and having relatively large livestock sectors.

While assigning cost shares to countries in this manner may seem fairly arbitrary, an argument in favor is that there is a remarkable degree of congruence among the cost shares reported for the seven country studies shown in Table 2. For the four developing-countries cases (India, Indonesia, China, and Brazil), cost shares ranged from 0.40 to 0.46 for labor, 0.22 to 0.25 for land, and 0.14 to 0.25 for livestock, while cost shares for fertilizer and machinery inputs were not more than 14% of total output. There was a tendency for the labor factor share to fall and the fertilizer and machinery input cost shares to rise with the level of agricultural development, reflecting embodiment of new technology in these inputs. But the fact that for these four developing and three developed countries, the input cost shares show a consistent pattern lends support to using them as representative of global agriculture. The seven countries are also relatively large producers, together accounting for 53% of global agricultural output in 2004–2006, according to the FAO data.

Another argument in favor of using the cost-share estimates reported in Table 2 as representative is that they are reasonably close to econometrically estimated production elasticities from studies that compared agricultural productivity across countries, which is implied from our assumptions about profit-maximization and long-run competitive equilibrium. Hayami and Ruttan (1985), Craig et al. (1997), and Wiebe et al. (2003) all find that labor had the highest production elasticity, followed by land and livestock. The Craig et al. (1997) and Wiebe et al. (2003) studies estimate production elasticities for land that are within the range of the land cost shares reported in Table 2, and about double those estimated by Hayami and Ruttan (1985). The difference between these econometric results can probably be attributed to the land quality variables included in the two more recent studies. However, econometric estimates of production elasticities from panel data on countries are not very robust and sensitive to model specification: all of the authors of these three econometric studies mention significant multicollinearity among the production factors. Further, none of the studies imposed constant returns to scale, and their estimates of scale economies in agriculture are mixed. However, it is not altogether clear how to interpret estimates of "scale economies" using country-level data. Economies of scale is a firm-level concept that does not apply to nations and requires comparisons among firms to test (Coelli and Rao, 2005).

2.5. Limitations

Some limitations of these calculations should be noted, given the nature of the data on which they are based. The first limitation is that I only compute rates of change in TFP. TFP "levels"

Table 2
Agricultural input cost shares

Study	Country/ period	Labor	Land & buildings	Livestock & feed	Machinery & energy	Chemicals & seed	Regions to which these factor shares are assigned:	Global production share (%)
Developing countries								
Evenson et al. (1999)	India 1967,1977, 1987 avg	0.46	0.23	0.25	0.01	0.04	South Asia Sub-Saharan Africa	16.4
Fuglie (2007)	Indonesia 1961–2005 avg	0.46	0.25	0.22	0.01	0.05	SE Asia, Oceania developing	5.2
Fan & Zhang (2002)	China 1961–1997 avg	0.40	0.22	0.23	0.06	0.09	NE Asia developing	16.7
Avila & Evenson (1995)	Brazil 1970, 1990 avg	0.43	0.22	0.14	0.14	0.07	LAC, MENA, South Africa	15.6
Developed countries								
Hayami & Ruttan (1985)	Japan 1965–1980 avg	0.39	0.23	0.10	0.05	0.23	NE Asia developed	2.0
Thirtle & Bottomley (1992)	U.K. 1967–1990 avg	0.30	0.17	0.26	0.17	0.10	Europe except former USSR	19.3
Ball et al. (1997)	USA 1961–2004 avg	0.20	0.19	0.28	0.14	0.18	N Amer, former USSR, Oceania developed	24.9
World		0.35	0.21	0.23	0.10	0.10	Average, weighted by production shares	100.0

cannot be compared across countries with this method. A second limitation is that I do not make adjustments for input quality changes other than for land. A third limitation is that revenue and cost shares are held constant over time. However, an examination of the output data show that for major commodity categories (cereal crops, oilcrops, fruits and vegetables, meat, milk, etc.) the global output growth rates were similar over the 1961–2006 period. On the input side there has been more movement in cost shares among the major input categories, but these changes occur gradually over decades. Thus, the likelihood of major biases in productivity measurement over a decade or two are not large, although this does remain a potential source of bias for long-term comparisons. The principal advantage of these TFP growth estimates, however, is that the calculations have a standardized quality. I use a common method, a common period of time for all countries, and a consistent set of definitions for determining factor shares. Moreover, I include 171 countries in the assessment, a nearly complete accounting of global agricultural production of crops and livestock.[3] I assess growth in individual countries as well as regions, and while regional averages may mask differences in performance among the countries within a region, the choice of aggregation into regions does not affect individual country results, unlike distance function measures (see Preckel et al., 1997, for a discussion of how aggregation can affect productivity growth estimates using distance functions). See Table 3 for a complete list of countries included in the analysis and their regional groupings.

[3] For the purpose of estimating long-run productivity trends, I aggregate some national data to create consistent political units over time. For example, data from the nations that formerly constituted Yugoslavia were aggregated in order to make comparisons with productivity before Yugoslavia's dissolution. Similarly, for Czechoslovakia, Ethiopia, and the USSR. Because some small island nations have incomplete or zero values for some agricultural data, I constructed three composite "countries" by aggregating available data for island states in the Lesser Antilles, Micronesia, and Polynesia, respectively. This also enables a more detailed examination of regional patterns of agricultural productivity growth.

3. Results

I first report a set of results showing global changes in agricultural productivity using "raw" data—with agricultural land unadjusted for quality and the output series unfiltered. Regional (and global) indices are derived by adding up output and inputs to the region level and then constructing a new set of input cost shares for the region. The regional cost shares are the weighted average of the country cost shares weighted by the country's share in total cost (revenue) for the region.

The "raw" average annual change in global output, input, and TFP over the 1970–1989 and 1990–2006 periods are shown in Table 4. I also show the average growth rates for output per worker, output per unit of agricultural land, and the average rate of yield increase in cereal grains (maize, rice, and wheat) for the same periods. The sources cited in the introduction claimed that global agricultural productivity growth slowed markedly between these two periods, and the evidence from the yield growth in cereal grains does seem to support this conclusion. However, for the agricultural sector as a whole, there is no evidence from the other figures in Table 4 that would indicate a slowdown in agricultural productivity growth. Rather, its appears that global agricultural productivity growth, when broadly measured, accelerated after 1990. The annual growth in TFP increased from 0.87% during 1970–1989 to 1.56% during

Table 3
Countries included in productivity analysis and regional groupings

Region	Countries			
Sub-Saharan Africa, developed	South Africa			
Sub-Saharan Africa, developing	Angola	Côte d'Ivoire	Madagascar	Senegal
	Benin	Djibouti	Malawi	Seychelles
	Botswana	Equatorial Guinea	Mali	Sierra Leone
	Burkina Faso	Ethiopia, former	Mauritania	Somalia
	Burundi	Gabon	Mauritius	Sudan
	Cameroon	Gambia	Mozambique	Swaziland
	Cape Verde	Ghana	Namibia	Tanzania
	Central African Rep.	Guinea	Niger	Togo
	Chad	Guinea-Bissau	Nigeria	Uganda
	Comoros	Kenya	Réunion	Zambia
	Congo	Lesotho	Rwanda	Zimbabwe
	Congo, Dem. Rep.	Liberia	Sao Tome and Principe	
Latin America and the Caribbean (LAC)	Argentina	Cuba	Honduras	Puerto Rico
	Bahamas	Dominican Rep.	Jamaica	Suriname
	Belize	Ecuador	Lesser Antilles	Trinidad and Tobago
	Bolivia	El Salvador	Mexico	Uruguay
	Brazil	French Guiana	Nicaragua	Venezuela
	Chile	Guatemala	Panama	
	Colombia	Guyana	Paraguay	
	Costa Rica	Haiti	Peru	
North America	Canada	United States of America		
Northeast Asia, developed	Japan	Korea, Rep.		
Northeast Asia, developing	China	Korea, DPR	Mongolia	
Southeast Asia	Brunei Darussalam	Laos	Philippines	Viet Nam
	Cambodia	Malaysia	Thailand	
	Indonesia	Myanmar	Timor-Leste	
South Asia	Afghanistan	Bhutan	Nepal	Sri Lanka
	Bangladesh	India	Pakistan	
Western Europe	Austria	France	Italy	Spain
	Belgium-Luxembourg	Germany	Malta	Sweden
	Cyprus	Greece	Netherlands	Switzerland
	Denmark	Iceland	Norway	United Kingdom
	Finland	Ireland	Portugal	
Eastern Europe	Albania	Czechoslovakia, former	Poland	Yugoslavia, former
	Bulgaria	Hungary	Romania	
Middle East and North Africa (MENA)	Algeria	Israel	Morocco	Tunisia
	Bahrain	Jordan	Oman	Turkey
	Egypt	Kuwait	Qatar	United Arab Emirates
	Iran	Lebanon	Saudi Arabia	Yemen
	Iraq	Libya	Syria	
Oceania, developed	Australia	New Zealand		
Oceania, developing	Fiji	New Caledonia	Polynesia	Vanuatu
	Micronesia	Papua New Guinea	Solomon Islands	
Former USSR countries (analysis of individual countries for 1992 and onward)	Armenia	Georgia	Lithuania	Turkmenistan
	Azerbaijan	Kazakhstan	Moldova	Ukraine
	Belarus	Kyrgyzstan	Russian Federation	Uzbekistan
	Estonia	Latvia	Tajikistan	USSR, former

1990–2006. This doubling of productivity growth mostly offset a decline in the growth rate of inputs employed in agriculture so that growth in output was only marginally lower in the 1990–2006 period. The partial productivity indices for agricultural labor and land also show little sign of slower growth: labor productivity growth accelerated while land productivity growth continued at about the same pace.

Fig. 1 plots the five-year average growth rates for global output, inputs, and TFP since 1962–1966. The long-run pattern shows that while growth in agricultural production inputs slowed through most of the period, the rate of increase in TFP accelerated to maintain real output growth at about 2% per annum. The exceptionally low rates of capital formation in global agriculture during the 1990s were due primarily to the rapid withdrawal of resources from agriculture in the countries of the former Soviet block. By the early 2000s, agricultural resources in this region had stabilized and there was a slight uptick in the rate of global input growth between 1997–2001 and 2002–2006. The growth decomposition shown in Fig. 1 was estimated with and without adjustments for land quality (and for different land

Table 4
Agricultural productivity indicators for world agriculture

Average annual growth rate by period (%)	Output index	Input index	TFP index	Output per worker	Output per hectare	Grain yield (t/ha)
1970–1989	2.24	1.36	0.87	1.25	1.96	2.29
1990–2006	2.06	0.50	1.56	1.51	1.95	1.35

Notes: Output per worker: FAO gross output index divided by number of persons working in agriculture.
Output per hectare: FAO gross output index divided by total arable land and permanent pasture.
Grain yield: Global production of maize, rice, and wheat divided by area harvested of these crops.
Total agricultural output is unfiltered and land input is not adjusted for quality.
Source: FAOSTAT and author's calculations.

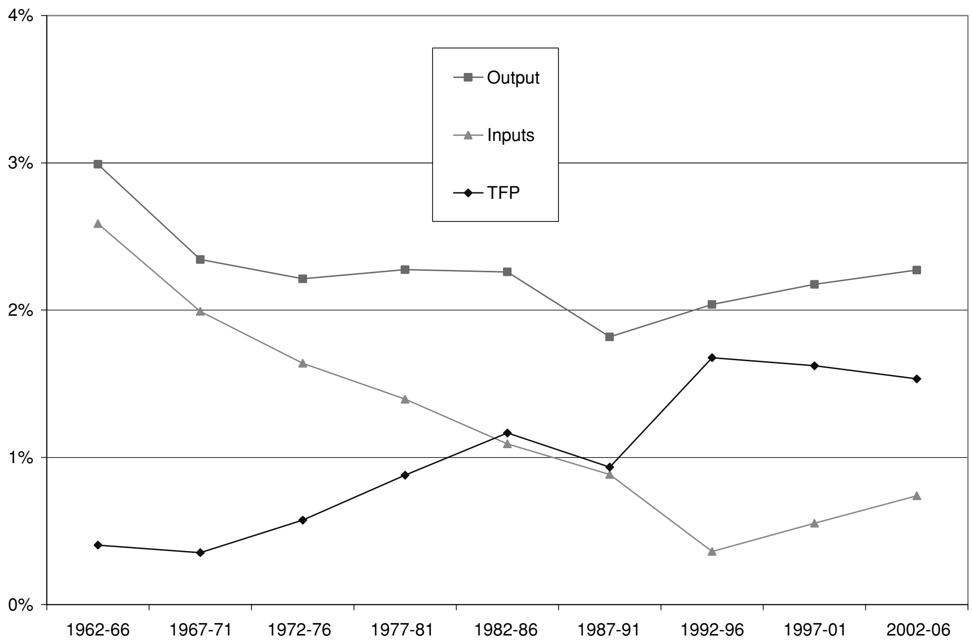

Fig. 1. Growth rates in global agricultural output, inputs, and TFP (five-year average annual %).

quality weights), and the results were robust to assumptions on land quality.

Table 5 disaggregates the global picture by region and selected countries and shows average growth rates for the indices by decade since 1970.[4] The regional results reveal that the global trend is hardly uniform, with three general patterns emerging:

(1) In developed countries, resources were being withdrawn from agriculture at an increasing rate, while TFP growth continued at historical levels (although the decade of the 1990s was above average in terms of TFP growth).
(2) In developing regions, productivity growth sharply accelerated in the 1980s and the decades following while input growth steadily slowed but was still positive. Two large developing countries in particular, China and Brazil, sustained exceptionally high TFP growth rates since the 1980s. Sub-Saharan Africa is a major exception to the general pattern, with TFP growth lagging significantly behind other developing regions.
(3) This dissolution of the Soviet Union imparted a major shock to agriculture in countries of the former USSR and its European allies: in the 1990s agricultural inputs were dramatically reduced in a short period of time and output fell; but by the early 2000s agricultural growth had resumed, led entirely by productivity gains in the sector.

Results at the subregional and country level (not shown) give further evidence on where agricultural productivity is growing and where it is not. Among developed countries, productivity growth as measured by TFP remained strong over the 2000–2006 period in every region except Oceania. Agricultural production in Australia has been adversely affected by a multi-year drought that depressed output growth even after filtering. But another important difference emerges among developed nations: in North America, agricultural output has continued

[4] Annual indices of TFP growth were estimated for each country for the entire 1961–2006 period (except for countries that made up the former Soviet Union, for which TFP indices were estimated only for 1992–2006). Due to space limitations, Table 5 only reports averages by decade since 1970 for major global regions.

Table 5
Agricultural output, input, and TFP growth by region

Average annual growth rate (%) by period	Output index (Smoothed with Hodrick–Prescott filter)				Input index (Land adjusted for quality)				TFP index			
	1970–1979	1980–1989	1990–1999	2000–2006	1970–1979	1980–1989	1990–1999	2000–2006	1970–1979	1980–1989	1990–1999	2000–2006
Sub-Saharan Africa	1.31	2.60	3.10	2.20	1.68	1.66	1.63	1.59	−0.37	0.94	1.47	0.61
Latin America & Caribbean	3.07	2.37	2.87	3.13	2.46	1.07	0.49	0.65	0.61	1.30	2.38	2.48
Brazil	3.83	3.73	3.29	4.41	4.38	0.60	0.29	0.75	−0.54	3.13	3.00	3.66
Middle East & North Africa	2.94	3.37	2.73	2.34	2.52	1.64	1.14	0.78	0.42	1.73	1.59	1.56
Northeast Asia, developed	2.15	1.03	−0.01	−0.01	0.29	−1.20	−2.57	−3.09	1.86	2.22	2.55	3.08
Northeast Asia, developing	3.11	4.55	5.06	3.85	2.60	1.98	1.06	0.43	0.51	2.57	4.00	3.42
China	3.09	4.60	5.17	3.87	3.27	2.13	1.39	0.65	−0.19	2.47	3.78	3.22
Southeast Asia	3.68	3.59	3.13	3.54	1.67	2.63	1.52	1.37	2.01	0.97	1.60	2.16
South Asia	2.56	3.39	3.00	2.19	1.90	1.37	1.29	0.83	0.66	2.02	1.71	1.36
India	2.69	3.52	2.94	2.00	1.89	1.42	1.19	0.57	0.80	2.10	1.74	1.43
North America	2.17	0.73	2.03	1.10	0.72	−0.63	−0.10	−0.65	1.46	1.36	2.13	1.75
Oceania	1.79	1.25	2.93	−0.04	0.71	0.23	1.03	0.21	1.08	1.02	1.90	−0.25
Western Europe	1.54	0.94	0.46	−0.35	0.08	−0.71	−1.50	−1.74	1.46	1.65	1.97	1.39
Eastern Europe	1.80	0.25	−2.18	−0.19	1.22	−0.08	−3.21	−0.78	0.58	0.33	1.03	0.58
USSR, former	1.32	0.98	−4.62	2.70	2.07	0.69	−6.23	−0.57	−0.74	0.29	1.60	3.28
Developing countries	2.82	3.46	3.64	3.09	2.27	1.79	1.34	1.01	0.55	1.67	2.31	2.08
Developed countries	1.88	0.86	1.21	0.39	0.26	−0.62	−1.04	−1.37	1.62	1.48	2.25	1.76
USSR & Eastern Europe	1.47	0.77	−3.88	1.81	1.93	0.49	−5.48	−0.29	−0.46	0.27	1.59	2.10
World	2.23	2.13	2.04	2.22	1.62	1.18	0.44	0.66	0.60	0.94	1.60	1.55

Source: Author's estimates.

to grow, while in Europe and northeast Asia (Japan and South Korea), real output is falling as resources are being withdrawn from agriculture faster than productivity is rising.

The strong and sustained productivity growth described here for a few large countries, especially Brazil and China, is broadly consistent with results from other studies. Brazil is reaping the benefits from a strong agricultural research system and, since the mid 1990s, macroeconomic stability (Avila, 2007). Using the Tornqvist index method, Gasquez et al. (2008) estimated average annual agricultural TFP growth in Brazil to be 2.51% over 1975–2005, similar to my estimate of 2.65%, and both show an acceleration of TFP growth over time. China has had success since the late 1970s with both institutional reform and technological change (Rozelle and Swinnen, 2004). Fan and Zhang (2002), also using the Tornqvist index method, estimated average annual TFP growth for Chinese agriculture at 2.6% during 1961–1997 with relatively slow growth until 1980 after which TFP rapidly accelerated. This study also shows an accelerating pace to TFP growth, although at a lower average rate. The lower estimate of TFP growth could reflect an "index number bias" from the use of fixed factor and revenue shares in countries undergoing rapid structural and technological change.

A fair number of midsize countries have also achieved respectable levels of agricultural productivity growth. South Korea, Malaysia, Peru, Chile, and Vietnam all achieved average agricultural TFP growth rates of over 2.8% per year over 1990–2006. However, with few exceptions, developing countries in Sub-Saharan Africa, the Caribbean, and Oceania continued to rely on resource-led agricultural growth rather than productivity, and as a consequence their agricultural sectors have performed poorly. Evenson and Fuglie (2007) got similar results of low agricultural TFP growth in these nations, and found TFP performance in developing-country agriculture to be strongly related to what they termed "technology capital," or the capacity to invent and extend new agricultural technology. Countries that had failed to establish minimally effective agricultural research and extension institutions were stuck in low-productive agriculture and were falling further behind the rest of the world.

4. Conclusions

Contrary to widely held perceptions, I find no evidence of a general slowdown in sector-wide agricultural TFP, at least through 2006. If anything, the growth rate in agricultural TFP accelerated in recent decades, due in no small part to rapid productivity gains in several developing countries, especially Brazil and China, and more recently to a recovery of agricultural growth in the countries of the former Soviet block. However, the results do show clear evidence of a slowdown in the growth in agricultural investment: the global agricultural resource base is still expanding but at a much slower rate than in the past. These two trends: accelerating TFP growth and decelerating input growth, have largely offset each other to keep the real output of global agriculture growing at about 2% per year since the 1960s. This finding has important implications for the appropriate supply-side policy response to the current agricultural price crisis.

One implication is that we should be optimistic about the prospects for global agriculture to respond to the current commodity price rises by increasing supply in the short run. For if it was TFP that was slowing down, it would likely take at least five to 10 years or even longer to influence this trend, given the long time lags between research investments and productivity growth. But the main trend identified in this article is a slowdown in the rate of growth in agricultural capital formation. This is at least in part a consequence of a long period of unfavorable prices facing producers, who found better opportunities for their capital outside of agriculture. It was also in part a consequence of the institutional changes in the countries of the former Soviet block that precipitated a rapid exit of resource from agriculture. The incentives afforded by the current high commodity prices and a resumption of agricultural growth in the former Soviet block countries should positively affect the rate of agricultural capital formation at the global level. So long as TFP growth continues at its recent historical pace, this should lead to an increased rate of real output growth in global agriculture in a relatively short period of time.

Despite this generally optimistic conclusion, it is also clear that agricultural productivity growth has been very uneven. While countries that have established effective agricultural R&D institutions have been able to sustain TFP growth in their agricultural sectors, many countries have not and as a consequence suffer from very low levels of agricultural productivity. This has not contributed to a *slowdown* in global TFP growth of the sector because their growth rates were never high to begin with. But this certainly has led to agriculture performing below its potential and has kept these countries poor. The largest group of countries in this low growth category is in Sub-Saharan Africa, but also extends to many countries in the Caribbean and Oceania as well as some others.

There is also evidence that agricultural productivity growth has been uneven across commodities. However, our ability to assess productivity growth at the commodity level is limited mainly to examining land yield trends since labor and capital inputs tend to be shared across multiple commodities in the production process. Thus, the slowing growth in cereal grain yield between 1970–1990 and 1990–2006 that was identified in the World Development Report does raise concerns that there is underinvestment (or low returns) to research directed at these commodities. But even here the picture is uneven, for decomposing cereal yield trends reveals that the slowdown affected wheat and rice yield only, with maize yield growth actually increasing after 1990. It is possible that the relatively strong performance in maize is due to the historically higher level of R&D investment for this crop because of the strong private-sector interest in breeding for hybrid maize (Fuglie et al., 1996). In any case the implication for R&D policy is quite different than if a productivity slowdown were occurring sector-wide. Rather than comprehensive changes to agricultural

R&D or investment policies, the uneven performance within the agricultural sector suggests a more selective approach that requires a clear understanding of the causes of low productivity growth in particular commodities and countries.

Acknowledgments and Disclaimer

The author would like to thank participants at a seminar at Yale University and two anonymous reviewers for their helpful comments on an earlier draft of the article as well as Shenggen Fan and Eldon Ball who provided unpublished data for this study. The views expressed here are the author's own and not necessarily those of the U.S. Department of Agriculture.

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